XIX. *On the Thermal Effects of Fluids in Motion.*—Part III. *On the Changes of Temperature experienced by bodies moving through Air. By Professor* W. Thomson, *A.M., LL.D., F.R.S. &c., and* J. P. Joule, *LL.D., F.R.S. &c.*

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This interesting branch of our researches has been prosecuted by us from time to time since 1856. In the spring of that year we commenced our experiments by trying the effect of whirling thermometers in the air. This process had been confidently recommended as a means of obtaining the temperature of the atmosphere, but we were sure that the plan was not absolutely correct, and one of us had, as early as 1847, explained the phenomena of "shooting stars" by the heat developed by bodies rushing into our atmosphere. In our early experiments we whirled a thermometer by means of a string, alternately quickly and slowly, and it was found that the thermometer was invariably higher after quick than after slow whirling, in some cases the difference amounting to as much as a degree Fahrenheit. We also succeeded in exhibiting the same phenomenon by whirling a thermo-electric junction. In 1857 we resumed the subject, using an apparatus consisting of a wheel worked by hand, communicating rapid rotation to an axle, at the extremity of which an arm carrying a thermometer, with its bulb outwards, was fixed. The distance between the centre of the axle and the thermometer bulb was 39 inches. The thermometers made use of were filled with ether or chloroform, and had, the smaller 275, and the larger 330 divisions to the degree C. The lengths of the cylindrical bulbs were $\frac{9}{10}$ and $1\frac{4}{10}$ inch, their diameters ·26 and ·48 of an inch respectively. The method of experimenting was to revolve the thermometer bulb at a certain velocity until we knew by experience that it had obtained the full thermal effect, then to stop it as suddenly as possible and observe the temperature.

Alternately with these observations others were made to ascertain the temperature after a slow velocity, the effect due to which was calculated from the other observations, on the hypothesis that it varied with the square of the velocity. In all cases the results in the Tables are means of several experiments.

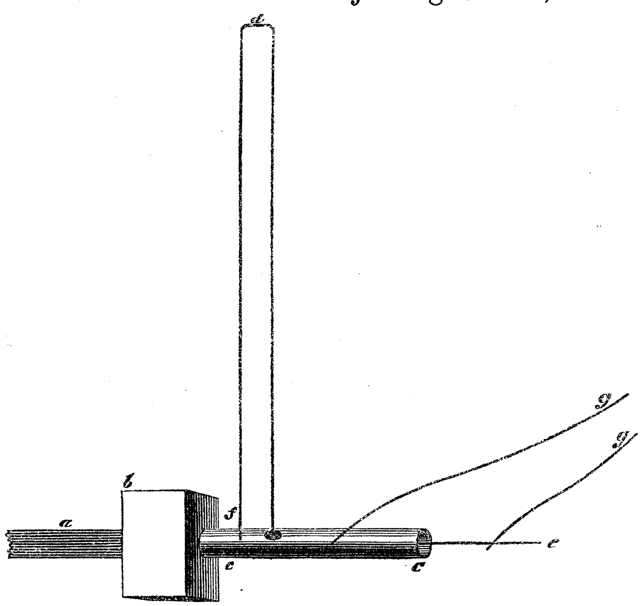
SERIES I.—Bulb ·26 inch diameter.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.
46·9 and 24	0°·082	0°·018	0°·1	148·8
51·5 and 24	0·098	0·018	0·116	151·2
68·1 and 24	0·151	0·018	0·169	165·6
72·7 and 24	0·191	0·018	0·209	159
78·7 and 24	0·228	0·018	0·246	158·6
84·8 and 24	0·251	0·018	0·269	163·5
103·7 and 24	0·333	0·018	0·351	175
130·2 and 24	0·531	0·018	0·549	175·7
133·2 and 24	0·607	0·018	0·625	168·5
145·4 and 24	0·676	0·018	0·694	174·6

SERIES II.—Bulb ·48 inch diameter.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.
36·3 and 18	0°·039	0°·015	0°·054	156·2
66·6 and 18	0·112	0·015	0·127	186·9
84·8 and 18	0·158	0·015	0·173	203·9
125·6 and 18	0·427	0·015	0·442	189

In the following experiments, made in the spring of 1859, thermo-electric junctions of copper and iron wire were whirled, and the effect measured by a THOMSON'S reflecting galvanometer. The arrangement will be understood from the adjoining sketch, where *a* is the axle of the whirling apparatus. *b* a block of wood placed on the end of the axle; to this is attached *c c'*, a copper tube, $\frac{3}{16}$ths of an inch in diameter, with a hole in its side. *d e* is a copper wire, which, entering the hole passes along the axis of the tube, from which it is insulated by non-conducting material. *d f* is an iron wire soldered at *d* to the copper wire. *g g* are thick copper wires, communicating at their remote ends with the galvanometer. They apply to the tube and wire with a springing force, perfect contact being maintained by keeping the touching surfaces clean, and lubricated with oil. A thin piece of wood, not drawn in the sketch, was attached to the block of wood. It was made to extend to within 1, 2, or 3 feet off *d*, according as the velocity was to be



slow or quick. The wires being tied to it, were prevented from twisting out of their proper position. The distance of d from the axis of revolution was generally 44 inches. The thermal value of the indications of the galvanometer was repeatedly ascertained by direct observations of the effect of heating the junctions.

The following Tables comprise the results of those experiments in which the junction was placed at right angles to the direction of its motion.

Series III.—Junction of wires $\frac{1}{100}$th of an inch in diameter.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.
53·6 and 21	0°·21	0°·037	0°·247	108
77·8 and 17·5	0·258	0·025	0·283	146·3
105 and 18	0·373	0·026	0·399	166·2
126·4 and 44·8	0·320	0·058	0·378	205·6
146 and 25	0·673	0·030	0·703	174·1
159·3 and 34	0·866	0·041	0·907	167·3
180 and 48	0·671	0·051	0·722	211
186·6 and 48·3	0·967	0·071	1·038	181·3
221 and 47	1·393	0·050	1·443	184
300·5 and 105·8	2·364	0·333	2·697	183
315·6 and 73	3·572	0·202	3·774	162·5
326·5 and 66·2	4·133	0·172	4·305	157·3
372·5 and 66·4	5·21	0·170	5·380	160·6

Series IV.—Junction of wires $\frac{1}{40}$th of an inch in diameter.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.
29 and 17·5	0°·022	0°·012	0°·034	157·2
46·2 and 15·5	0·157	0·026	0·183	108
73·7 and 16·75	0·281	0·024	0·305	133·5
90 and 17	0·363	0·013	0·376	146·8
139·1 and 26	0·61	0·021	0·631	175·1
155·6 and 26	0·878	0·024	0·902	163·9
246·4 and 31	1·482	0·023	1·505	200·8
262·6 and 35	2·087	0·045	2·132	179·8

Series V.—Junction of wires $\frac{1}{17 \cdot 5}$th of an inch in diameter.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.
64·03 and 33·96	0°·127	0°·049	0°·176	152·6
91·48 and 41·17	0·204	0·073	0·277	173·8
134·9 and 51	0·67	0·112	0·782	152·5
160·73 and 47·34	0·685	0·097	0·782	181·8
177·9 and 48·25	0·863	0·100	0·963	181·3
208 and 44	1·469	0·071	1·540	168

SERIES VI.—Junction of wires $\frac{1}{8\cdot7}$th of an inch in diameter.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.
93·1 and 39	0°·198	0°·042	0°·240	190
109·6 and 52·4	0·239	0·072	0·311	196·5
133·96 and 58·3	0·432	0·100	0·532	183
163·7 and 55·2	0·654	0·084	0·738	190·5

From the above Tables it is manifest that the thermal effect increases nearly with the square of the velocity; it is, however, a little greater at low velocities than accords with this law. Taking, therefore, the means of the foregoing results, and rejecting all those obtained from a velocity under 100 feet per second, we obtain the following summary:—

Material of the whirled cylinder.	Diameter.	Velocity due to 1° Cent.
Glass	0·26	173·45
Glass	0·48	189
Copper-iron . . .	0·01	177·54
Copper-iron . . .	0·025	179·9
Copper-iron . . .	0·057	170·9
Copper-iron . . .	0·115	190
	Mean	180·13

It may be inferred from the above that the thermal effect is independent of the kind of material whirled, provided its surface is smooth; and that it is likewise independent of the diameter of the cylinder moving in a direction perpendicular to its length.

In the next experiments we whirled the junctions parallel to the direction of motion.

SERIES VII.

Diameter of wire.	Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.	Means.
·01	123·4 and 45·2	0°·415	0°·064	0°·479	178°·3	172·1
	186·7 and 54·2	1·160	0·107	1·267	165·9	
·057	126·5 and 39·6	0·59	0·058	0·648	157·1	160·55
	206·6 and 44	1·518	0·072	1·59	164	
·115	100·5 and 44·8	0·215	0·053	0·268	194·1	182·7
	182·7 and 50	1·053	0·085	1·138	171·3	

The general mean of the velocities due to 1° Cent. is therefore 171·78, which is not notably different from the result obtained when the wire was placed at right angles to the direction of motion. The absence of any considerable effect arising from the shape of the body whirled, was also shown by the following results obtained with a junction of flattened wires a quarter of an inch broad and one-thirtieth of an inch thick.

Series VIII.

Position of junction.	Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.	Mean.
Flat side against the air...............	85·8 and 40	0°·165	0°·046	0°·211	186·6	
	156·5 and 52	0·683	0·085	0·768	178·6	180·6
	164·4 and 48	0·736	0·074	0·810	182·6	
Thin edge against the air...............	182·4 and 54·3	0·811	0·074	0·885	193·9	

The general mean of all the foregoing results is 179·15 feet per 1° Cent. The phenomena hitherto observed seemed to point to the effect of stopping air as a cause, since 145 feet per second is the velocity of air equivalent to the quantity of heat required to raise its substance, under constant pressure, by 1° Cent. temperature; and it was reasonable to infer that a portion of the effect was lost by radiation. The following experiments, made with a junction of fine wires covered loosely with cotton-wool or tow, enabled us to eliminate all effects but those due to stopped air. Their results will be found to agree closely with theory.

Series IX.

Position of junction.	Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C.	Mean.
Cotton-wool closely tied about the junction of fine wires	91·3 and 34	0°·25	0°·04	0°·29	169·6	
	112 and 26	0·447	0·025	0·472	162·8	
	135·8 and 40·6	1·37	0·14	1·51	110·5	148·76
	140·3 and 24	0·823	0·024	0·847	152·4	
	167·6 and 43·5	1·188	0·085	1·273	148·5	
Junction of fine wires placed in a small wicker basket filled with cotton-wool or tow	94·1 and 35	0·494	0·079	0·573	124	
	95·7 and 25·3	0·426	0·032	0·458	141·1	
	105·5 and 27·6	0·33	0·026	0·356	168·3	144·53
	113·5 and 33	0·409	0·038	0·447	169·5	
	116·8 and 33	0·639	0·055	0·694	140·1	
	116·8 and 47·4	0·739	0·145	0·884	124·2	

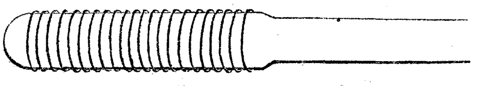
When the junction was placed in the basket, without any cotton-wool or tow, a velocity of 160·1 ft. per second was required to give 1°. N.B. The basket was so open that its orifices amounted to half the entire area.

In several of our experiments with very slow velocities there appeared to be a greater evolution of heat than could be due to the stopping of air. This circumstance induced us to try various modifications of the surface of the whirled body. In the first instance we covered the bulb of the thermometer used in the second series of experiments with five folds of writing-paper, and then obtained the following results:—

Series X.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C., or V_{1°, on the hypothesis that $V_{1^\circ}=\frac{v}{\sqrt{t}}$.
36·3 and 18	0°·045	0°·015	0°·060	148·2
51·5 and 18	0·115	0·015	0·130	142·8
72·6 and 18	0·146	0·015	0·161	180·9
118 and 18	0·385	0·015	0·400	186·6

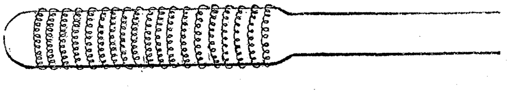
It will be seen from the last column that the effect at slow velocities was greater than that which might have been anticipated. We were thus led to try the effect of a further increase of what we may call "fluid friction." In the next series the bulb was wrapped with fine iron wire.



Series XI.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C., or V_{1°, on the hypothesis that $V_{1^\circ}=\frac{v}{\sqrt{t}}$.
15·36 and 7·68	0°·022	0°·008	0°·030	88·8
23·04 and 15·36	0·069	0·03	0·099	73·2
30·71 and 15·36	0·118	0·03	0·148	79·8
46·08 and 15·36	0·177	0·03	0·207	101·3
69·12 and 15·36	0·267	0·03	0·297	126·8
111·34 and 15·36	0·530	0·03	0·560	148·8
126·72 and 15·36	0·598	0·03	0·628	160
153·55 and 15·36	0·850+	0·03	0·880+	163.4—

In the next experiments the bulb was wrapped with a spiral of fine brass wire.



Series XII.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C., or V_{1°, on the hypothesis that $V_{1^\circ}=\frac{v}{\sqrt{t}}$.
7·68 and 1·92	0°·006	0°·002	0°·008	86·3
15·36 and 7·68	0·033	0·008	0·041	75·8
23·04 and 15·36	0·070	0·041	0·111	69·1
30·71 and 15·36	0·105	0·041	0·146	80·3
46·08 and 19·2	0·120	0·075	0·195	104·4
76·8 and 23·04	0·203	0·111	0·314	137·1
115·18 and 23·04	0·570	0·111	0·681	139·5
148·78 and 76·8	0·488	0·314	0·802	166·2

The last columns of the above Tables clearly indicate that at slow velocities a source

of heat exists besides that from stopped air. It is also evident that, as the velocity increases, this thermal cause decreases; for at a velocity of 150 feet per second the thermal effect is such as would be due to the influence of stopped air alone.

In prosecuting still further this part of our subject we made the following arrangement. A disc of mill-board, 32 inches in diameter, was fixed to the end of the axis of the whirling apparatus. An ether thermometer, whose bulb was one-fourth of an inch in diameter, was tied by its stem to the face of the disc, so that the bulb was 15 inches distant from the axis of revolution, and 1 inch from the margin of the disc. In the following Table the first five experiments were made with the above arrangement, but in the last two a thermo-electric junction of thin copper and iron wires, tied closely to the mill-board, was substituted for the ether thermometer.

SERIES XIII.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C., or V_{1°, on the hypothesis that $V_{1^\circ}=\frac{v}{\sqrt{t}}$.
3·15 and ·5	0°·029	0°·005	0°·034	17·1
7·85 and 3·15	0·027	0·034	0·061	31·7
15·7 and 7·85	0·052	0·061	0·113	46·6
31·4 and 15·7	0·022	0·113	0·135	85·5
Thermo-electric junction: 63·3 and 27·4	0·106	0·120	0·226	133·3
Thermo-electric junction: 90·2 and 25	0·286	0·116	0·402	142·3

The surface of the mill-board disc being rather rough, it was judged desirable to make similar experiments with a disc of sheet zinc. This was perfectly smooth, $36\frac{1}{2}$ inches in diameter. The thermometer bulb was fixed at 17·1 inches distance from the axis.

SERIES XIV.

Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Estimated effect of low velocity.	Thermal effect of high velocity.	Velocity due to 1° C., or V_{1°, on the hypothesis that $V_{1^\circ}=\frac{v}{\sqrt{t}}$.
1·71 and ·57	0°·024	0°·010	0°·034	9·2
3·42 and 1·71	0·017	0·034	0·051	15·1
8·55 and 3·42	0·027	0·051	0·078	30·7
17·1 and 8·55	0·023	0·078	0·101	53·8
34·2 and 17·1	0·046	0·102	0·148	88·8
57·28 and 17·1	0·070	0·102	0·172	138·3

The last columns of the two foregoing Tables clearly show the inapplicability of the law of the increase of temperature with the square of the velocity, at low velocities. The thermal effect appears even to increase at a slower rate than simply with the velocity. This phenomenon may, we think, be ascribed to the internal fluid friction of the particles

of air among themselves, which Professor STOKES has proved to exist, by his researches on the motion of pendulums. We may easily apprehend that in such experiments as our last, the entire face of the disc is covered with a film of air, which revolves along with it at very slow velocities. As the velocity increases there will still be a film of air adhering to the disc, but with the difference that it will be constantly replaced by fresh stopped air, the thermal effect of which will ultimately be the only recognizable phenomenon.

A very interesting and important branch of our subject was to inquire into the thermal phenomena which take place at the surface of a sphere passing rapidly through air. Some of our experiments on this subject have been made by blowing air from a large bellows against a ball; others by whirling a ball or sphere in the air by means of the apparatus already described. We shall commence by describing the latter, in some of which a thermo-electric junction was employed, and in others an ether thermometer.

SERIES XV.—Wooden ball 2 inches in diameter, with a thermo-electric junction of fine copper and iron wires made even with the surface.

Position of the junction in respect to the direction of motion.	Velocities in alternate experiments.	Difference of thermal effect.
In front, or anterior	75·6 and 23·1	$\overset{\circ}{0}$·269
	118·4 and 23·1	0·517
	141·5 and 39·5	0·745
At the side, or equatorial...	74 and 28·5	−0·146
	115 and 26·3	0·283
	120 and 40	0·020
In the rear, or posterior ...	71·5 and 25	0·093
	112·4 and 19·3	0·414
	113·7 and 42	0·280

In the above experiments differential results for the several pairs of velocities are alone given, so that, although one of the quantities has a negative sign, there is no proof of actual cooling effect. In the next experiments we whirled a thin glass globe, 3·58 inches in diameter, placed at a distance of 38 inches from the axle of the apparatus. The small bulb of an ether thermometer was kept in contact with the glass.

Series XVI.

Position of the bulb of the thermometer in respect to the direction of motion.	Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Thermal effect due to low velocity.	Thermal effect due to high velocity.
In front of the globe	3·84 and 1·92	$0\overset{\circ}{\cdot}002$	$0\overset{\circ}{\cdot}001$	$0\overset{\circ}{\cdot}003$
	7·68 and 3·84	0·007	0·003	0·010
	15·36 and 7·68	0·143	0·010	0·153
	23·04 and 15·36	0·106	0·153	0·259
	38·4 and 15·36	0·133	0·153	0·286
	57·5 and 15·36	0·211	0·153	0·364
At the side of the globe ...	3·84 and 1·92	0·029	0·007	0·036
	7·68 and 3·84	0·109	0·036	0·145
	15·36 and 7·68	0·138	0·145	0·283
	23·04 and 7·68	0·181	0·145	0·326
	38·4 and 23·04	0·000	0·326	0·326
	57·5 and 23·04	0·087	0·326	0·413
In the rear of the globe ...	3·84 and 1·92	0·011	0·004	0·015
	7·68 and 3·84	0·024	0·015	0·039
	15·36 and 7·68	0·147	0·039	0·186
	23·04 and 15·36	0·076	0·186	0·262
	38·4 and 15·36	0·062	0·186	0·248
	57·5 and 15·36	0·091	0·186	0·277
	70·92 and 15·36	0·204	0·186	0·390

In the next experiments, a 12-inch globe, such as is used in schools, was fixed at a distance of 3 feet from the axis of the revolving apparatus. The ether thermometer was generally employed, as in the last series, but for the highest velocity a thermo-electric junction of thin wires placed close to the globe registered the thermal effect.

Series XVII.

Measurer of heat, and its position in respect to the direction of the motion.		Velocities in the alternate experiments, in feet per second.	Difference of thermal effect.	Thermal effect due to low velocity.	Thermal effect due to high velocity.
Anterior.	Ether thermometer ...	3·72 and 1·24	$0\overset{\circ}{\cdot}019$	$0\overset{\circ}{\cdot}009$ estim[d].	$0\overset{\circ}{\cdot}028$
		7·44 and 3·72	0·008	0·028	0·036
		14·88 and 7·44	0·028	0·036	0·064
	Thermo-electric junction	39·68 and 7·44	0·200	0·036	0·236
Equatorial.	Ether thermometer ...	3·72 and 1·24	0·007	0·003 estim[d].	0·010
		7·44 and 3·72	0·013	0·010	0·023
		14·88 and 7·44	0·024	0·023	0·047
	Thermo-electric junction	39·37 and 7·44	0·170	0·023	0·193
Posterior.	Ether thermometer ...	3·72 and 1·24	0·024	0·012 estim[d].	0·036
		7·44 and 3·72	0·022	0·036	0·058
		14·88 and 7·44	0·046	0·058	0·104
	Thermo-electric junction	37·2 and 7·44	0·140	0·058	0·198

In the experiments in which air was blown against a sphere, we made use of a large organ-bellows, from which a constant stream of air could be kept up at velocities dependent upon the weights laid on. In our first trials, the air issued from a circular

aperture $2\frac{1}{2}$ inches in diameter, and the ball was placed, at half an inch distance, in front of the aperture. We shall, as before, call that point of the ball which was nearest the wind, the Anterior Pole; the most sheltered point, the Posterior Pole; and the intermediate part, the Equator. The balls were furnished with thermo-electric junctions of thin copper and iron wires, made flat with the surface, the junctions being in each case 90° apart from one another.

Series XVIII.—$\frac{1}{2}$-inch Wooden Ball.

Velocity of air.

68 ft. per sec. ... Equator 0°·114 colder than Anterior Pole ... Posterior Pole 0°·067 colder than Equator.

Series XIX.—1-inch Wooden Ball.

Velocity of air.		
1·2	... Equator 0°·088 warmer than Anterior Pole.	
3·6	... Equator 0·129 warmer than Anterior Pole	... Posterior Pole 0°·03 warmer than Equator.
7·2	... Equator 0·160 warmer than Anterior Pole	... Posterior Pole 0·022 warmer than Equator.
14·4	... Equator 0·120 warmer than Anterior Pole	... Posterior Pole 0·018 colder than Equator.
28·8	... Equator 0·056 warmer than Anterior Pole	... Posterior Pole 0·018 colder than Equator.
36	... Equator 0·008 colder than Anterior Pole.	
48	... Equator 0·035 colder than Anterior Pole.	
57·6	... Equator 0·056 colder than Anterior Pole......	Posterior Pole 0·090 colder than Equator.
73	... Equator 0·245 colder than Anterior Pole.	
105	... Equator 0·380 colder than Anterior Pole......	Posterior Pole 0·232 colder than Equator.

In our next series, one junction was placed within the bellows, and the other in contact with the different parts of the 1-inch ball. All the results will be seen to indicate, as might have been anticipated, that the junction within the bellows was warmer than any part of the ball.

Series XX.

Velocity of air.	Pressure of air in the bellows, in inches of water.	Cold of Anterior Pole, in respect to the inner junction.	Cold of Equator, in respect to the inner junction.	Cold of Posterior Pole, in respect to the inner junction.
2·4	0·003 estimated	0°·098	0°·065	0°·028
3·6	0·006 estimated	0·094	0·065	0·028
7·2	0·025 estimated	0·083	0·103	0·060
14·4	0·105 estimated	0·110	0·089	0·109
28·8	0·42 estimated	0·102	......	0·112
73	2·7 estimated	0·188	0·309	0·300
105	5·6 measured	0·195	......	0·360

A further modification of the experiments was made by placing a glass tube 3 feet long and of $1\frac{1}{2}$-inch interior diameter, within the aperture, so that two-thirds of the tube was inside, and one-third outside of the bellows. A ball furnished with junctions 90° distant from each other was placed within the tube.

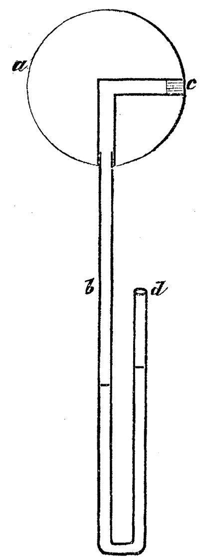
Series XXI.—Wooden Ball, 1 inch diameter.

Velocity of air.		
1·8	Equator 0°·045 warmer than Anterior Pole	Posterior Pole 0°·052 warmer than Equator.
2·7	Equator 0·056 warmer than Anterior Pole	Posterior Pole 0·052 warmer than Equator.
5·4	Equator 0·074 warmer than Anterior Pole	Posterior Pole 0·035 warmer than Equator.
10·8	Equator 0·052 warmer than Anterior Pole	Posterior Pole 0·017 warmer than Equator.
21·6	Equator 0·037 warmer than Anterior Pole	Posterior Pole 0·008 colder than Equator.
43·2	Equator 0·011 warmer than Anterior Pole	Posterior Pole 0·013 colder than Equator.
54	Equator 0·019 colder than Anterior Pole	Posterior Pole 0·014 colder than Equator.
62		Posterior Pole 0·023 colder than Equator.
83·8		Posterior Pole 0·041 colder than Equator.
108	Equator 0·091 colder than Anterior Pole	Posterior Pole 0·086 colder than Equator.

Series XXII.—Wooden Ball, ½ inch diameter.

Velocity of air.		
1·8	Equator 0°·048 warmer than Anterior Pole	Posterior Pole 0°·050 warmer than Equator.
5·4	Equator 0·030 warmer than Anterior Pole	Posterior Pole 0·047 warmer than Equator.
10·8	Equator 0·023 warmer than Anterior Pole	Posterior Pole 0·031 warmer than Equator.
21·6	Equator 0·008 warmer than Anterior Pole	Posterior Pole 0·012 warmer than Equator.
43·2	Equator 0·006 colder than Anterior Pole	Posterior Pole 0·009 warmer than Equator.
54	Equator 0·019 colder than Anterior Pole	Posterior Pole 0·006 colder than Equator.
62	Equator 0·026 colder than Anterior Pole	Posterior Pole 0·014 colder than Equator.
83·8	Equator 0·040 colder than Anterior Pole	Posterior Pole 0·031 colder than Equator.
108	Equator 0·068 colder than Anterior Pole	Posterior Pole 0·050 colder than Equator.

The general result is that at slow velocities of air there is a gradual increase of temperature from the anterior to the posterior pole, but the reverse at high velocities. We observed a great effect for slow velocities at the commencement of an experiment, which gradually declined on continued blowing. This phenomenon was apparently owing to circumstances in connexion with the temperature of the orifice and of the bellows.



The causes of the thermal effects on the surface of balls slowly passing through air are very complicated, as they arise from the effects of stopped air, fluid friction, and varied pressures. In order, if possible, to throw some light on these, we made the following observations:—

1st. That when the 12-inch globe passed through the air at the velocity of about 12 feet per second or under, the air at the equatorial part moved in the reverse direction. We did not observe the velocity, if it existed, at which this phenomenon ceased to take place*.

2nd. An ivory ball, 1·7 inch diameter, had holes drilled from points of the surface 90° asunder, which holes met at the centre of the ball. Into the lower one (see adjoining figure) a bent glass tube, partly filled with water, was cemented; in the other, at *c*, a porous wooden plug was placed. It was then found that when *c* was made the anterior pole in a blast from the bellows, a pressure was experienced able to

* See 'Proceedings of the Royal Society,' June 18, 1857, p. 558.

produce a difference of level in the tubes *b* and *d* equal to 2·5 inches. When *c* was put in the equatorial position, there was, on the contrary, a suction equal to 1·2 inch. When *c* was made the posterior pole there was also a suction, equal, however, to only 0·1 inch. Having tied a thick fold of silk over the orifice *d*, we tried the same thing in a strong breeze of wind, when we found that on making *c* the anterior pole, we had a pressure amounting to 0·6 of an inch; on making *c* equatorial, a suction of 0·3; and on making *c* the posterior pole, a suction of 0·05 inch.

We have not hitherto been able to detect any change in the thermal effect, owing to the whistling sound of wire or other bodies rapidly whirled. We think it possible that this vibratory action decreases the resistance and the evolution of heat. Some of the sounds produced are interesting and worthy of further investigation. When a small piece of paper was attached to the revolving wire, we obtained a continuous succession of loud cracks similar to those of a whip.

But although this and other parts of our subject remain to be cleared up, we believe that it will be found that at all high velocities the thermal effect arises entirely from stopped air, and thus is independent of the shape and mass of the body, and of the temperature and density of the atmosphere. From some experiments described in the 'Proceedings of the Royal Society' of June 19, 1856, p. 183, we inferred that a body placed in a stream of air moving with a velocity of 1780 feet per second, was raised 137° C. above the temperature of that stream. This gives 152 feet per second as the velocity due to 1°, while our direct results, given in the present paper, indicate 179.

It must be obvious that a thermometer placed in the wind registers the temperature of the air, plus the greater portion, but not the whole, of the temperature due to the *vis viva* of its motion. In a place perfectly sheltered from the wind, the temperature of a thermometer immersed in the air will be that of the wind, plus the whole temperature due to the *vis viva* of the moving air. In accordance with this we have found that a thermometer placed in a sheltered situation, such as on the top of a wall opposite the wind, indicates a higher temperature than when it is exposed to the blast. A minute examination of these phenomena cannot fail to interest the meteorologist.